Estimating early mortality and implications for reference points for the Atlantic menhaden stock

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Background

Recruitment processes are of critical importance for fish population dynamics and fisheries management because they determine the productivity of a stock, sustainable yields that can be obtained, and optimal exploitation rates, which provide reference points for management (Quinn and Deriso 1999). The productivity of a stock is greatly affected by survival during early life stages, and small changes in daily survival rates can lead to large changes in year class strength. Productivity of the stock-recruitment relationship may change substantially over time, which causes changes in sustainable fishing mortality rates (e.g., Hare et al. 2010). Thus, understanding factors that cause variation in early life survival, and their incorporation into fishery management reference points, is important for improving fisheries management and stock assessment. We propose to use several surveys to estimate early survival and understand mechanisms affecting the stock-recruitment relationship for Atlantic menhaden and incorporate these factors into time-varying reference points for management of this stock.

Target species and stock status— Atlantic menhaden, *Brevoortia tyrannus*, is a pelagic fish that ranges from Florida to Maine, spawns in coastal waters, and uses estuaries as its juvenile nursery habitat (Ahernholz 1991). The coastal population segregates geographically by size and age, with the larger and older fish to the north, and has seasonal migrations in conjunction with spawning activity (Ahernholz 1991). Spawning begins at the northern end of the range in late-summer, prior to the southward migration. Adults begin their southward fall migration beginning in about September. Spawning occurs southward along the coast during the migration. As a result, estuaries along the coast can receive larvae from multiple spawning locations and temporal events (Quinlan et al. 1999). Thus, the processes that govern Atlantic menhaden recruitment are complex and likely to vary over space and time, but variability in recruitment is likely due to three probable causes with respect to different life stages (Houde et al. 2011). First, overfishing may have reduced adult menhaden abundance to levels that now impede recruitment. Second, menhaden spawning offshore may now be experiencing relatively poor oceanographic conditions on the continental shelf that are unfavorable for survival of eggs and larvae, or conditions that do not favor transport of larvae to estuarine nursery habitats including Chesapeake Bay. Last, the estuarine-dependent age-0 juveniles may now be experiencing poor water quality conditions, which reduce production potential leading to lower growth and survival and diminished recruitment success.

The coastwide Atlantic menhaden stock is assessed by the National Marine Fisheries Service (NMFS) and managed by the Atlantic States Marine Fisheries Commission (ASMFC). Fishery-dependent data have been collected and processed by NMFS since the 1950s, and NMFS staff members serve as the lead analysts for the stock assessments (ASMFC 2010). The most recent assessment used a statistical catch-at-age model, which was fitted to data including commercial reduction and bait fishery landings and age compositions, a juvenile abundance index based on state seine surveys, and an adult abundance index based on the Potomac River Fisheries Commission's fishery-dependent data. Since the early 1990s, both recruitment and abundance of age 2+ fish estimated in the stock assessment have been low. The single coastwide

stock, according to recent stock assessments, is not overfished but experienced overfishing in 2008 (ASMFC 2010). Although not declared overfished in the recent stock assessment, fishing mortality is relatively high and the stock biomass is judged to be at a low level, which concerns managers and stakeholders who seek to conserve the fishery and ecosystem services provided by this valuable forage species.

Problems— Recruitment is one of the most important processes governing population dynamics and fisheries management. Currently the stock assessment and management of Atlantic menhaden does not rely on estimation of a stock-recruitment function and does not include information on environmental forcing of recruitment (Figure 1a). Successful recruitment relies on both production of an adequate number of eggs and environmental conditions that promote high survival rates. Small changes in larval mortality rates can result in extremely large differences in year class strength given the same spawning stock size (Houde 2002). Management of most species, including menhaden, does not allow for time-varying productivity, which can negatively affect fishery performance (A'mar et al. 2009, Brunel et al. 2010)

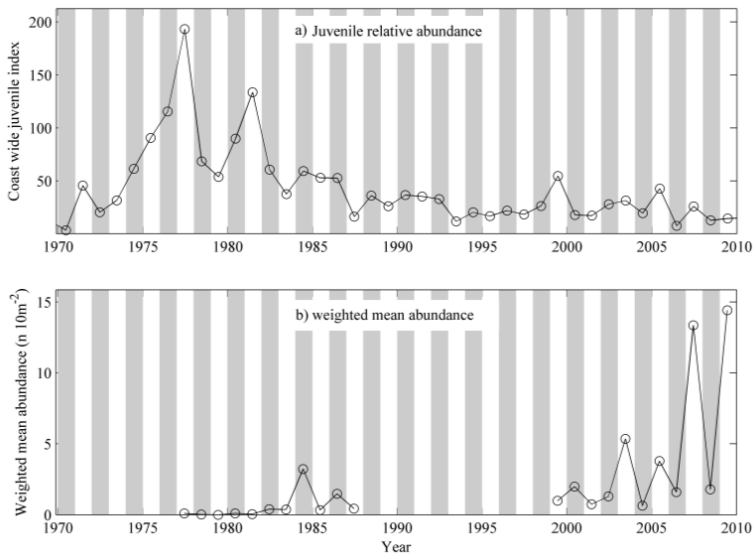

Figure 1 Coast wide juvenile menhaden index developed from beach seine surveys (a), and weighted mean abundance of menhaden larvae from MARMAP (1977-1987) and ECOMON (1999-) between Cape Hatteras and Nova Scotia (b).

Natural mortality rates of early life stages are likely to have spatial and temporal dimensions of variability, reflecting fluctuations in the probability of survival in space and time. Coast wide juvenile menhaden abundance has been low since the 1990s after a high period from late 1970s – mid 1980s (Figure 1a). Data from NEFSC plankton surveys between Cape Hatteras and Nova Scotia suggested the coast wide weighted larval abundance of menhaden larvae showed decadal fluctuations (Figure 1b) which were low in the late-1970s with an increasing trend through the 1980s and another increasing trend in the 2000s. ***A key question is why these decadal patterns in larval abundance are not apparent in juvenile abundance***. ***Can we incorporate trends in larval production into reference point estimation?***

Changes in environment— Hydrographic conditions along the northwest Atlantic coast between Cape Hatteras and Nova Scotia are influenced by the Gulf Stream, Labrador Current, and large-scale climate forces that have been changing over the last four decades. The ecosystem has seen an increasing range of sea surface temperatures (Friedland and Hare 2007) and a general freshening of shelf waters from the Labrador Sea to the Mid-Atlantic Bight (Mountain 2003; Greene and Pershing 2007). These changes have led to changes in the biological communities of the ecosystem. Fish communities on the northeast US shelf have shifted northward (Nye et al. 2009, Hare et al. 2010, Lucey and Nye 2010).

Lower trophic levels, including phytoplankton and zooplankton, have exhibited responses to changing hydrographic conditions as well. These changes have included changes in zooplankton community structure (Pershing et al. 2005, Kane 2007) and abundance trends (Kane 2011). Phytoplankton abundances have also shown shifts in abundance across the Southern New England (Kane 2011) and the Mid-Atlantic Bight (see Figure 2) regions. Satellite-derived chlorophyll a concentrations in the MAB declined from 2002 – 2006. In addition to changes in community structure and abundance of the lower trophic levels, seasonal occurrence and abundance are changing as well. Small copepod species, such as *Centropages typicus*, which typically peaked in September – December before 2000, recently exhibited a peak that was delayed by ~2-3 months. Peak abundance shifted to January – February after 2000, corresponding to the shift in peak timing of northward along-shore current velocities (Figure 3, Bi et al. submitted). In conjunction, Atlantic menhaden larvae cumulative percent frequency of occurrence has significantly increased during September – October from 1999 to 2009. Atlantic menhaden and its congener species feed primarily on phytoplankton (dinoflagellates and diatoms) at small sizes (Govoni et al. 1983) and small copepods like *C. typicus* and *C. hamatus* as they grow (Kjelson et al. 1975, Govoni et al. 1983, Chen et al. 1992). Therefore, changes in abundance, community structure, and seasonal timing of the lower trophic levels may lead to a mismatch with the occurrence of larval Atlantic menhaden on the northeast US shelf. ***The potential mismatch in timing of the seasonal peak between Atlantic menhaden larvae and C. typicus or decrease in phytoplankton abundance after 2000 may have led to slower growth, which in turn may have led to lower recruitment for Atlantic menhaden in the 2000s.***

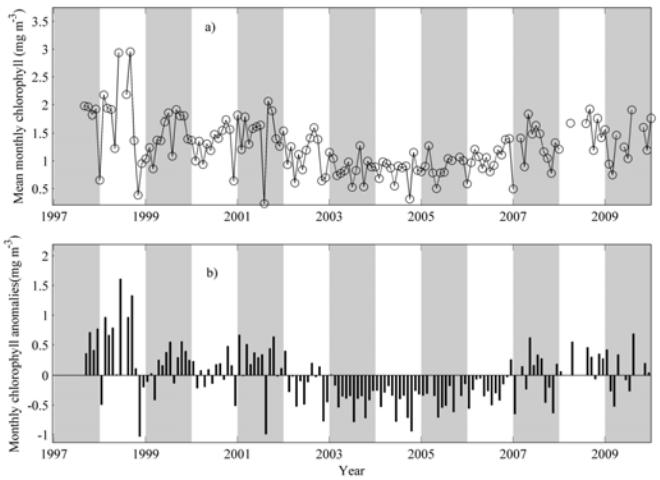

Figure 2 Mean monthly chlorophyll a concentration 35 – 42°N within 1° nearshore using SeaWiFS data (a); and monthly chlorophyll anomalies (b). Note lower levels of chlorophyll from 2002 – 2006.

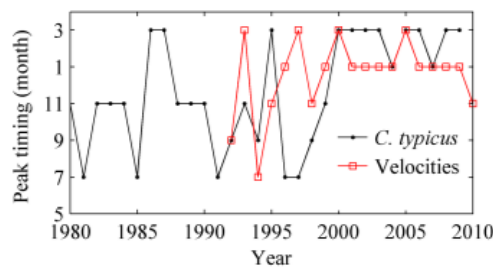

Figure 3 Peak timing of *Centropages typicus*, the main prey for menhaden larvae (black line with dots) and northward alongshore water movement (red line with squares).

The rationale for exploring mortality of Atlantic menhaden larvae in relation to environmental changes to improve the stock assessment is clear: 1) survival of menhaden larvae is likely to be affected by environmental changes, 2) the decadal pattern in relative larval abundance is likely a response to changes in lower trophic levels, and 3) information on changes in productivity of the stock can help inform reference points. Therefore, modeling changes in larval mortality provides an opportunity to incorporate environmental processes into the stock assessment and determination of stock status.

The objectives of this study are to: 1) estimate menhaden larvae mortality taking advantage of the larval data from NEFSC plankton surveys and juvenile menhaden abundance from coast wide beach seine surveys; 2) evaluate early mortality in relation to biological and oceanographic changes using NEFSC plankton survey data, satellite-derived sea surface temperature, and chlorophyll a; and 3) incorporate changes in larval mortality into stock-recruitment models and development of time-varying reference points.

Methods

Oceanographic data sources— We will assemble data from *in-situ* field observations and various satellite-derived observations on the northeast U.S. continental shelf.

Shelfwide NEFSC ichthyoplankton surveys - Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program sampled ichthyoplankton at approximately 200 stations eight times per year during 1977 – 1987, and since 1999, ECOMON has sampled ~120 stations, six times per year, using similar sampling protocols as MARMAP. Additional surveys in1988-1999 covered both Southern New England and the Mid-Atlantic Bight. Larvae from these NOAA surveys have been identified and enumerated. All hydrographic data and plankton data are available through the NOAA NEFSC.

Sea Surface Temperature (*SST*) - Monthly high resolution (4km) sea surface temperature is available from NOAA National Oceanographic Data Center (NODC). This dataset combines various SST data products from several different satellite sensors and *in situ* observations at a relatively high spatial resolution since 1981.

Ocean color data - Chlorophyll data from SeaWiFS are available from NASA ocean color website from 1997 – 2010. Data from CZCS: 1978 – 1986, and Aqua-MODIS: 2000 – 2010 are also available. We recognize the difficulty in combining chlorophyll data from different sensors, thus we will use SeaWiFS data to investigate the relationship between chlorophyll *a* and larval survival and then qualitatively examine the relationships with historical data.

Estimating relative mortality for early life stages — The larval mortality of Atlantic menhaden will be estimated in two ways. The first approach is to estimate relative mortality. We will use either weighted annual mean abundance over the entire survey area as a proxy for relative larvae abundance. The coast wide juvenile index will be used as a proxy for juvenile abundance. Comparing relative larvae abundance to relative juvenile abundance in the same year, we can estimate relative mortality rate. The second approach will take advantage of length measurements for each individual larvae, so that potential variation in larval size will be accounted for. Growth will be modeled as a function of temperature and food, and each individual will be projected to the mean size of juvenile menhaden at age 0. The Pareto function (Houde 2002) will be used to describe the proportion of larvae surviving at age/size. Then an iterative function will be used to estimate the best fit for the parameters by minimizing the sum of squares between observed and modeled values. Larval survival rate will be estimated through this procedure. We will compare the results from two different approaches and decipher the common pattern, with special emphasis on the decadal scale.

Relating environmental conditions to larval survival — We will examine changes in temperature, chlorophyll a, and zooplankton. 1) For temperature and chlorophyll data, we will examine mean temperature and chlorophyll as well as the spatial and temporal patterns using Empirical Orthogonal Functions (EOF). EOF is a multivariate ordination technique for reducing the dimensions of multivariate data without losing inherent information. 2) For zooplankton, we will focus on the interannual variability of peak timing and biomass for small copepods such as *C. typics* and *C. hamatus* that are the main food source for menhaden larvae. 3) For larval

survival, correlative analyses between time series of environmental indices and larval mortality will be used to explore how environmental factors influence larval mortality. 4) For large scale forcing, the time series of environmental indices will be related to larval abundance and large scale climate indices such as the North Atlantic Oscillation.

Incorporation into stock-assessment — We will use the relationships identified between larval mortality and environmental factors to develop time-varying fishery reference points. Ricker, Beverton-Holt, and Shepherd stock-recruitment models will be constructed that predict recruitment based on spawning stock biomass (Quinn and Deriso, 1999). Parameters of these stock-recruitment models govern the degree of productivity, density-dependence, and overcompensation exhibited by the stock. It is conceivable that any of these parameters could be affected by the environment. Therefore, we will allow one parameter in each model to vary as a linear or log-linear function of an environmental factor. We will determine the best parameter and model form using AIC model selection (Burnham and Anderson 2002). Model estimates will then be used to calculate maximum sustainable yield-based reference points (biomass and fishing mortality) by applying the methods of Shepherd (1982).

Timeline

Year 1 – Estimate larval mortality and examine environmental changes.
Year 2 – Examine larval mortality in relation to environmental changes and incorporate information into reference point estimation.

Benefits

This work 1) brings together oceanographers and stock assessment scientists from agencies (***Schueller***: lead analyst for the menhaden stock assessment at SEFSC; ***Nesslage***: menhaden stock assessment scientist at ASMFC; ***Walsh***: research fishery biologist at NEFSC) and academia (***Bi***: oceanographer at CBL; ***Wilberg***: stock assessment expert at CBL) to develop process-based indices, 2) provides a unique opportunity for scientists to work at the boundary between oceanography and population dynamics to directly contribute to the stock assessment process, and 3) provides training of a graduate student.

Deliverables

- Time series of relative larval mortality for consideration as ancillary information in the Atlantic menhaden stock assessment.
- Environmental indices that influence temporal dynamics of Atlantic menhaden larval mortality.
- Development of new reference points that incorporate environmental effects.
- Attendance of oceanographers and ecologists at stock assessment meetings.
- Peer-reviewed publications describing Atlantic menhaden larval mortality, reference point estimation, and the related environmental processes.

Results from prior funding

Walsh: For project 11-03, NEFSC scientists worked with Jim Churchill (WHOI) to evaluate the overlap between the acoustic Atlantic herring survey and the spawning distribution of herring, which was determined by backtracking captured larvae in a numerical circulation model to an estimated hatching location. This work was presented at the 2012 Atlantic herring assessment.

Schueller received FY2012 funds for a FATE project titled Effect of hypoxia on the gulf menhaden fishery and implications for stock assessment. Money has been transferred to the NRC, and a postdoctoral associate has been selected. The associate started work in September of 2012.

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